EXPLORING THE SOCIO-ECONOMIC BENEFITS OF A HIGH-SPEED RAIL NETWORK LINK BETWEEN GAUTENG AND LIMPOPO

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ABSTRACT

This study explores the socio-economic impact of a proposed High-Speed Rail (HSR) network connecting Gauteng and Limpopo provinces in South Africa. It highlights the inefficiencies of the current transportation system, including congestion and limited rail services, which hamper economic growth. The HSR project will leverage advanced technologies like Artificial Intelligence (AI) and the Internet of Things (IoT), Intelligent Transportation Systems (ITS), Radio Frequency Identification (RFID) Tags and Head-up Display (HUD) to improve efficiency, safety, and sustainability. Planned in two phases, it is expected to create 195,644 skilled jobs, requiring an investment of R152.46 billion, which will have a regional economic return of R611.5 billion, significantly strengthening the regional economic growth, reducing travel times and boosting industrial growth in Limpopo's Special Economic Zones while improving access to essential services. The HSR seeks to lower carbon emissions, narrow the urban-rural divide, and promote regional inclusivity, demonstrating its potential to drive sustainable development in South Africa.

Keywords: High-Speed Rail (HSR), Job creation, Advanced technologies, Environmental sustainability, Regional economic growth.

1. INTRODUCTION

South Africa's transportation network, particularly the Gauteng-Limpopo corridor, is crucial for economic activities and trade, although it suffers from persistent congestion and inefficiencies that increase travel times and costs for businesses and commuters (Brand and Drewes, 2020; McKay, 2020; Mkhabele, 2024). The heavy traffic also contributes to air pollution and ecosystem degradation (Wang et al., 2023). The proposed High-Speed Rail (HSR) network linking Gauteng and Limpopo seeks to alleviate these challenges by shifting passengers and freight from road to rail systems, enhancing transportation efficiency. The provincial governments have approved the HSR implementation protocol

document for the HSR, which seeks to boost inter-provincial connectivity, reduce travel times, and attract investment to transform cities into dynamic hubs. According to Mahope (2024), the HSR is anticipated to have stations in Pretoria, Hammanskraal, Bela-Bela, Modimolle, Mookgopong, Polokwane, Louis Trichardt and Musina.

The HSR project is expected to drive significant socio-economic advancements in South Africa by creating jobs in construction, operations, and maintenance, as well as providing employment opportunities for local communities (Deel-Smith, 2022; Mathaba, 2024). Improved transportation links can facilitate easier market access, attract investments, and increase regional competitiveness while enhancing environmental sustainability by reducing reliance on fossil fuel vehicles and lowering greenhouse gas emissions (Kwilinski et al., 2024). Prioritising a sustainable transport mode of this magnitude will help South Africa meet its climate goals and promote economic growth (Kustar et al., 2023). Studying the proposed HSR project is vital to understanding its viability and potential benefits for the nation's socio-economic landscape.

1.1 Background of the Study

South Africa's transportation network is critical in connecting regions and boosting economic activities, especially in the Gauteng-Limpopo corridor, a key trade route for trade and the movement of goods and people (Parliamentary Monitoring Group, 2023; Department of Roads and Transport Province of Gauteng, 2023). However, both provinces face high unemployment and a transportation system plagued by inefficiencies such as congestion, inadequate passenger rail services, and environmental degradation caused by heavy reliance on road transport. These issues hinder economic growth and increase regional disparities. The proposed HSR network between Gauteng and Limpopo seeks to transform transportation through advanced technologies such as AI, ITS, RFID, HUD and IoT. This project will enhance connectivity, shorten travel times, create jobs, and stimulate regional economic growth while promoting environmental sustainability and regional inclusivity.

1.2 Problem Statement

The rail transportation between Gauteng and Limpopo is inefficient, with limited passenger rail options and relying heavily on road transport. This leads to congestion, longer travel times, and environmental pollution. These issues hinder economic growth, worsen regional inequalities, and limit access to services and job opportunities. Limpopo's economy remains isolated despite its potential and contribution to high unemployment rates in South Africa. Addressing these challenges requires a transformative solution that would improve connectivity, boost job creation, and minimize environmental impact so as to stimulate regional socio-economic development within these regions.

1.3 Aim of the Paper

This paper aims to explore the socio-economic benefits of the proposed HSR network linking Gauteng and Limpopo, focusing on the potential of job creation, stimulating regional economic growth, and promoting environmental sustainability.

1.4 Scope of the Study

This study focuses on the proposed HSR network linking Gauteng and Limpopo and its socio-economic and environmental effects. It analyses the project's two phases, which are

from Pretoria to Polokwane and then Polokwane to Musina, incorporating advanced technologies like AI, IoT, RFID, HUD and IITS. The study will evaluate the HSR's potential to reduce travel times, create job opportunities, stimulate the regional economy, and support the Makhado-Musina Special Economic Zones. It will assess environmental benefits such as decreased carbon emissions and enhanced sustainability. The scope will include an analysis of demographic, employment statistics and economic impacts, drawing lessons from global HSR projects and South Africa's Gautrain for a successful implementation.

2. RATIONALE FOR THE STUDY

2.1 Existing Rail Network and Usage

The rail network connecting Gauteng and Limpopo provinces in South Africa primarily focuses on moving freight, with limited passenger options, making travel difficult for many people (Chilamphuma, 2024). To address this, both provincial governments plan to build an HSR link that will make journeys faster and more convenient, boost the local economy, and create jobs. Currently, most goods transported between the two provinces, like minerals and agricultural products, rely on the rail system, leaving passengers with few options and a heavy reliance on road transport. This reliance has led to traffic jams and longer trip times, making clear the need for improved rail services that can benefit everyone.

2.2 Necessity and Significance of the Study

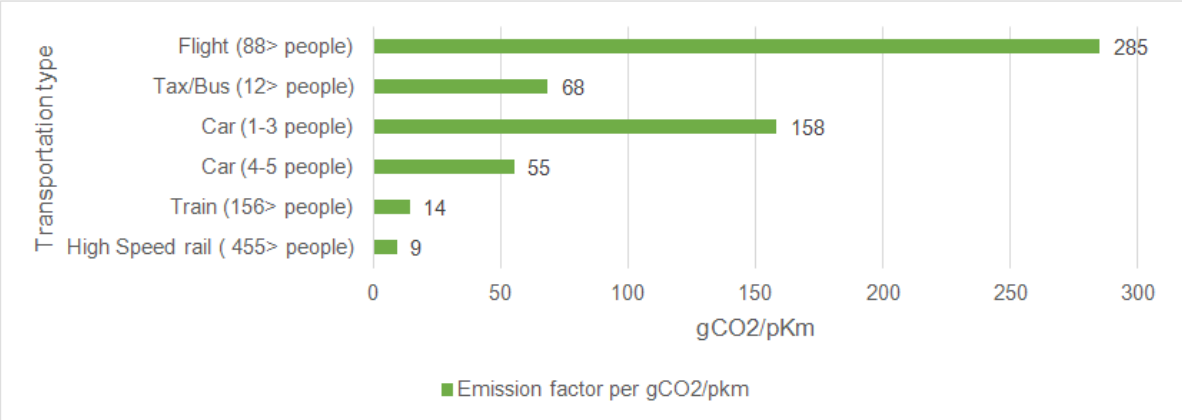
The HSR project connecting Gauteng and Limpopo is vital for addressing socioeconomic challenges between the two regions. According to StatsSA (2022), Gauteng contributes over 33% to South Africa's GDP, while Limpopo contributes just 7.7%, despite Limpopo's rich natural resources, the province remains underdeveloped and economically isolated. The projects seek to enhance regional connectivity, thus promoting economic growth. By improving transportation links, the HSR could facilitate the efficient movement of goods and people, stimulating industrial growth and creating job opportunities in places like Limpopo's SEZ, such as Musina-Makhado Special Economic Zones (SEZ) (Rodrigues, 2022; Su et al., 2024). This could boost tourism to key attractions such as Kruger National Park, addressing the high unemployment rates in both provinces, especially in Gauteng, which faced a loss of 66 000 jobs and has an unemployment rate of 34% (Rekord, 2024; Libera, 2024).

The HSR linking Gauteng and Limpopo would address existing transportation inefficiencies between both provinces, offering modern commuting alternatives that would enhance worker accessibility while reducing travel times. By incorporating advanced technologies such as RFID tags, AI, IoT, HUD and ITS, the project seeks to improve rail operation efficiency and safety. RFID tags are utilized for asset tracking, while AI-powered maintenance helps prevent accidents. IoT sensors can optimize train operations, and HUD technology provides real-time information to operators, minimizing human errors (Malinga, 2024; Schultz, 2024).

2.3 Environmental and Sustainability Benefits

The HSR project is a crucial initiative that aligns with South Africa's goal of reducing CO_2 emissions in accordance with the Paris Agreement. The Gautrain Management Agency (GMA) has invested R1 billion in IT developments to support this system (Malinga, 2024). Research by Ritchie, (2023), as shown in Figure 1, indicates that rail transport is

substantially more eco-friendly, producing 80% less CO_2 per passenger kilometer than other transportation modes. Trains are particularly efficient compared to road and air transport, which can carry 1 to 88 passengers and emit 55 to 185 gCO_2 per passenger kilometer, as shown in the accompanying table. Figure 1 further highlights that HSR can significantly reduce CO2 emissions by accommodating more significant numbers of passengers up to 455 with an emission rate of only 9 gCO_2 per passenger kilometer. Transitioning commuters and goods to rail transport has the potential to decrease annual emissions.



Source: Baron et al. (2011); Ritchie (2023)

Figure 1: CO_2 emission from passenger transport

The HSR project offers significant environmental benefits alongside opportunities for economic growth and social cohesion. The HSR is expected to reduce carbon emissions and ease traffic congestion by providing a more sustainable alternative to road and air travel, promoting public rail transportation. Additionally, it has the potential to narrow the urban-rural divide in the targeted regions, improving access to education, healthcare, and job opportunities in Gauteng and Limpopo, which supports regional inclusivity (Department of Transport, 2018; Lawrence et al., 2024). However, the successful execution of the HSR project faces several challenges. According to Brodowicz (2024), significant hurdles include the high initial costs, land acquisition difficulties, and the necessity of ensuring adequate demand to justify the investment. By effectively addressing these challenges, the HSR could catalyze sustainable regional development and economic growth in South Africa, particularly benefiting Gauteng and Limpopo.

2.4 Advanced Technological Aspect

A 2020 CGTN article highlights that advanced technology is crucial for the success of the HSR, similar to the HSR project proposed between Gauteng and Limpopo. Technological innovations will enhance safety, efficiency, and sustainability, benefiting the local economy and creating long-term jobs. Advanced technologies such as AI, IoT, RFID, HUD and ITS are key to optimizing train operations and improving passenger experiences.

- Artificial Intelligence (AI) in HSR: AI will enhance safety and passenger experiences in the proposed HSR through predictive maintenance and real-time updates, which reduce disruptions and maximize infrastructure lifespan. The growing demand for skilled AI professionals in the rail sector in South Africa will offer educational opportunities, fostering job creation and economic growth.

- The Internet of Things (IoT) in HSR: IoT will enhance the proposed HSR management through real-time sensor monitoring. It will enable proactive maintenance and greener transportation by optimizing energy use. It will also create new job opportunities and simplify travel by connecting various modes of transportation.

- Intelligent Transportation Systems (ITS) in HSR: ITS utilize advanced technologies like AI and IoT to enhance the safety and efficiency of HSR networks. By monitoring traffic in real-time and optimizing train schedules, ITS minimizes delays and improves the overall travel experience for passengers (Corman et al., 2016; Prasad & Jain, 2024).

- Radio Frequency Identification (RFID) Tags for Train and Cargo Tracking: A 2024 article by Malinga reveals that the new HSR link between Gauteng and Limpopo will use RFID technology for better train and freight management, enabling real-time tracking of train cars and luggage. This technology also streamlines ticketing and boarding through RFID-enabled smart cards, reducing wait times and enhancing customer satisfaction.

- Head-up Display (HUD) Technology for Train Operators: HUD technology enhances safety and efficiency in HSR systems by projecting vital information directly onto the windshield, enabling train operators to focus on the track. This real-time data reduces distractions, aids decision-making, and improves situational awareness, even under challenging conditions.

3. FRAMEWORK OF THE PROPOSED HSR NETWORK

3.1 Route and Coverage

The HSR project is a joint initiative by Gauteng and Limpopo provincial governments, which have established an Implementation Protocol and appointed a Joint Project Manager for its execution, in consultation with the Department of Transport (Limpopo Provincial Government, 2024). The project will take place in two phases. As shown in Figure 2, phase one will be from Pretoria to Polokwane, covering 240km, and will continue to Musina as the second phase, also passing through the currently planned Makhado-Musina SEZ (Taylor, 2024; Sunday Times, 2024). The project will connect Pretoria in Gauteng to Musina in Limpopo, spanning approximately 420 kilometers (Taylor, 2024). According to Mahope (2024), the key towns and stations of the proposed HSR will be from Pretoria, Bela-Bela, Modimolle, Mookgophong, Polokwane, Louis Trichardt and Musina. Figure 2 illustrates the proposed HSR route, while Table 1 presents the population and employment statistics for the regions along this route.

Table 1 shows that Gauteng and Limpopo face high unemployment rates of 34% and 31.4%, with youth unemployment at 45.5%. The proposed HSR network, located in the heart of both provinces, as shown in Figure 2, which is also expected to benefit 15 million in Gauteng and 6.5 million in Limpopo, including 7 million unemployed people in both provinces. The HSR is expected to benefit over 4 million people in Phase 1 and more than half a million in Phase 2. It is also expected to benefit more than 1 million unemployed people in Phase 1 and over 200,000 in Phase 2. The HSR project will be constructed in two phases and cover an area with a population of 4.9 million, including 1.3 million unemployed and a 26.3% overall unemployment rate, alongside a youth unemployment rate of 33.5%. This highlights the urgent need for job creation in these regions.

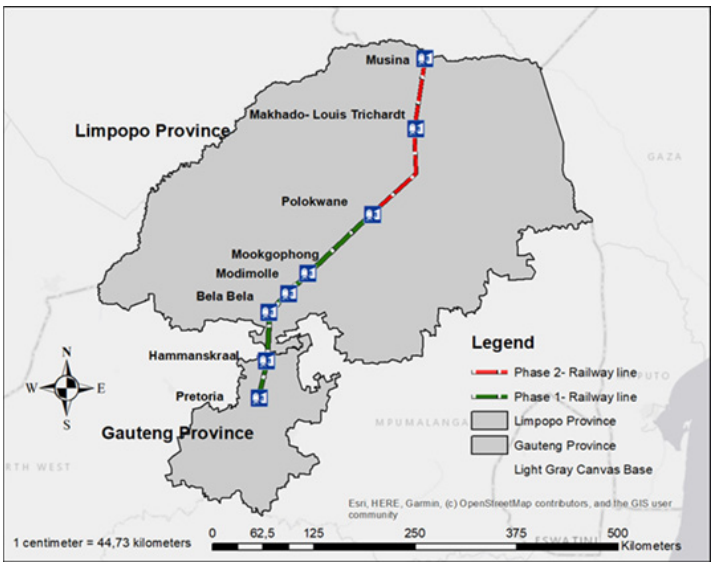


Figure 2: Route of the proposed HSR

Table 1: Demographic and employment statistics for the proposed rail station municipal area

Municipal Area for The Rail Station Proposed	Population	Unemployment Rate	Youth Unemployment Rate	Total Number of Unemployed People
Phase one				
Gauteng Province				
1. City of Tshwane Metropolitan (Pretoria and Hammanskraal)	3 555 741	24,2%	32,6%	860,490
Limpopo Province				
2. Bela-Bela	69 676	22,5%	29,8%	15,678
3. Modimolle	68 513	22,2%	28,9%	15,210
4. Mookgopong	35 640	23,5%	29,2%	8,376
5. Polokwane	628 999	32,4%	42%	203,796
Sub Total	4 358 569	25%	32.5%	1 103 550
Phase two				
6. Makhado (Louis Trichardt)	502 452	36,7%	49,6%	184,400
7. Musina	122 123	18,7%	22,5%	22,838
Sub Total	624 575	27.7%	36.05%	207 238
Total for phase 1 and 2	4 983 144	26.3%	33.5%	1,310,788

Source: StatsSA 2022

According to StatsSA (2023), Gauteng significantly impacts South Africa's economy, contributing 33% to the national GDP. Within this province, the City of Tshwane Metropolitan Municipality, including Pretoria and Hammanskraal, benefits from a strong economy supported by its rail network and transportation infrastructure, which are essential for job creation and workforce access. As shown in Table 2, various sectors drive economic growth in these areas, with such regional economies majorly responsible for existing jobs and the region's economy. The rail system's efficient movement of goods and people is vital for these regional economies.

In contrast, Limpopo contributes 7.7% to the national GDP, with the proposed HSR project planned to improve the existing rail route through key towns from Bela-Bela to Musina, which borders Zimbabwe. This infrastructure development seeks to enhance regional connectivity, stimulate regional economic growth, and create job opportunities, boosting the province's GDP. As shown in Table 2, Gauteng focuses on IT, technology, and automotive manufacturing, while Limpopo focuses on agriculture, logistics, and trade,

taking advantage of its proximity to neighboring countries and illustrating South Africa's diverse economic landscape.

Table 2: Gauteng and Limpopo railway route key regional economy contributors

Gauteng	Limpopo
Public sector	Public sector
Automotive manufacturing	Tourism and Hospitality
Higher education and research	Industry
Tourism and hospitality	Agriculture
Financial services and real estate	Mining
IT and technology sectors	Logistics and Trade
Agriculture and Agro-processing	Manufacturing
Informal and retail sectors	Forestry
Infrastructure development	Services, Retail and Financial
Emerging tourism potential	

Source: Derived from Japan International Cooperation Agency (JICA), Japan International Consultants for Transportation Co., Ltd., & Mitsubishi Research Institute, Inc. 2013

4. JOB CREATION AND REGIONAL IMPACT OF HSR

4.1 Construction Job Creation and Timeline

According to research, including that done by Ollivier et al. (2014), HSR projects usually take about five to seven years to build. This timeframe matches the estimates provided by the Gauteng and Limpopo governments, which suggest that the proposed HSR project may take around five years to complete once its feasibility study is approved at the end of 2025 (ATTA, 2024; EZA, 2024).

The construction costs for HSR vary significantly from country to country. According to Nash (2015), China's costs are notably lower than those of Europe and other international countries, making it the lowest in construction costs. South Africa's Gautrain project, which covers a distance of 80 km and the construction costed approximately R26.4 billion (R330 million p/km), providing valuable insights for the proposed HSR project (Gautrain Management Agency (GMA), 2015). This aligns with the costs seen in global HSR, especially since Gautrain's maximum speed is only 160 km/h compared to HSR, which reaches 250 km/h.

Studies such as Campos and Ginés (2009) and Nash (2015) indicate that the construction cost of HSR in China is estimated to be €5,7 million (R110 million) to €18.8 million (R363 million) p/km, which is in the same range as that of the Gautrain's construction costs which were R330 million p/km from is approval in September of 2006 (GMA, 2015). These insights are crucial for the proposed HSR in Gauteng and Limpopo, where the investments in HSR have significant economic benefits. Furthermore, according to USHSR (2023) and the Rail Passengers Association (2021), each $1 billion (R18.7 billion) investment creates an estimated 10,000 construction jobs and 24,000 high-skilled jobs.

The first phase of the proposed HSR, covering 240 km from Pretoria to Polokwane, is estimated to begin in 2026 and be completed by 2033. As shown in Table 3 below, with respect to the maximum investment cost required, being R363 million, Phase 1 will create approximately 46,595 construction jobs at a cost of R87.12 billion. The second phase, which currently does not have a start-by date, will extend 180 km from Polokwane to Musina, costing about R65.2 billion and generating around 34,944 construction jobs. The total project cost is expected to be R152.46 billion, potentially creating 81,539 construction jobs.

Table 3: Cost and workforce analysis for Gauteng and Limpopo HSR Project

Phase	Distance (km)	Cost (billion ZAR)	Workforce Creation
Phase 1	240	Cost = Distance X Average Cost/km (1) Cost = 240 X R363 million/km Cost = R87.12 billion	10 000 jobs = R18.7 billion T_{cost} = 87.12 billion Workforce = $(\frac{Total\ Cost}{Cost\ per\ 1\ billion})$ X 10,000 (2) Workforce = $(\frac{87.12}{18.7})$ X 10,000 Workforce = 46 595 jobs
Phase 2	180	Cost = R65.2 billion	Workforce = 34 944 jobs
Total Project	420	Total Cost = R152.46 billion	Workforce = 81 539 jobs

4.2 Economic Benefits and Job Creation

According to international lessons learned, the HSR connecting Gauteng and Limpopo is projected to create over 80,000 construction jobs. The Rail Passengers Association reported in 2021 that for every $1 billion (R18.7 billion) invested in HSR, 24,000 high-skilled jobs are generated, with an estimated economic return of $4 (R75) for every $1 (R18.7) invested, which supports local communities along the rail lines and the entire country which, this includes additional jobs in various fields, as outlined in Table 2. HSR not only creates direct jobs in the rail network but also stimulates growth in industries providing transportation products and services.

According to Yang et al. (2023), HSR significantly boosts the regional economy through investments. In Table 4 below, using an average investment estimated at R363 million p/km. This investment could create approximately 195,644 high-skilled jobs across multiple sectors. As shown in Table 4, the project's first phase of 240km will require an investment of R87.12 billion, creating 111,803 high-skilled jobs, while Phase 2 of 180km, needing R65.34 billion, is expected to generate 83,841 high-skilled jobs. This investment of R152.46 billion will subsequently have an economic benefit of R611.5 billion, which will enhance the economy and benefit higher learning institutions providing relevant training within the two provinces.

Table 4: Cost and high-skilled job creation for Gauteng and Limpopo HSR Project

Phase	Distance (km)	Cost (billion ZAR)	High-Skilled Jobs Created
Phase 1	240	87.12	111 803
Phase 2	180	65.34	83 841
Total Project	420	152.46	195 644
Economic Return		611.5	

As shown in Table 4 above, for the R152.46 billion invested in the proposed HSR, an economic return of R611.5 billion will be acquired. This investment can significantly impact the regional economies of the towns served by the HSR and, ultimately, the country. As shown in Table 5, the project could create 195,644 high-skill jobs and 81,539 construction jobs in Gauteng and Limpopo. As unemployed people exceed 1.3 million, this investment may reduce the combined unemployment rate in the HSR route from 26.3% to 24,7% during construction and from 26,3% to 22,4% through high-skilled jobs, resulting in a 3.9% decrease.

Table 5: Employment statistics overview: Job creation and unemployment metrics

Province	Population	Unem-ployment rate	Total number of unemployed people	High-skilled Jobs	Unemployment after construction	Unemployment after High-Skilled Jobs
Phase 1	4 358 569	25%	1 103 550	195 655 X $\frac{4\,358\,569}{4\,983\,144}$ 171 225	x = 25% X (1-r_1) (3) $1\text{-}r_1 = \frac{24.7\%}{25.3\%}$ 24.4%	22.2%
Phase 2	624 575	27.7%	207 238	24 419	27%	24.6%
Total	4 983 144	26.3%	1 310 788	195 644	24.7%%	22.4%

The HSR has great potential to increase Gauteng and Limpopo's regional economy and GDP. As shown in Table 6, the HSR is estimated to decrease the number of unemployed people in construction jobs from 1,310,788 to 1,229,249, representing a 1.6% unemployment rate drop. It is also estimated that the number of unemployed people in the proposed HSR route will decrease from 1,310,788 to 1,115,144, constituting a 3.9% reduction in high-skilled jobs. This reduction highlights the positive impact of the HSR on job creation and improves the regional economy within the city routes.

Table 6: Job creation and alleviated unemployment rate

Job type Created	Jobs Created	Remaining Unemployed People	Remaining Rate	Alleviated Unemployment Rate
Construction jobs	81 539	1 229 249	24.7%	1.6%
High-skilled jobs	195 644	1 115 144	22.4%	3.9%

The HSR will significantly reduce travel times, enabling Gauteng residents to seek jobs in Limpopo. This increased accessibility will boost regional economies as more people travel for work, education, and health services, improving their quality of life. The construction phase will also stimulate local economies and attract investment, while the operational phase will enhance tourism in towns such as Bela-Bela, Polokwane and Musina, drawing visitors and their associated spending. The project promotes environmental sustainability as it will lower carbon emissions and ease highway congestion, resulting in a cleaner environment. Ultimately, the HSR is about connecting regions, creating employment and fostering a brighter future for the people of Gauteng and Limpopo, thus positively impacting South Africa.

5. CONCLUSION

The study explores the socio-economic benefits of the HSR link between Gauteng and Limpopo, highlighting the challenges that can be addressed through its introduction. While Gauteng, contributing over 33% to South Africa's GDP, contrasts with Limpopo's 7.7%, despite Limpopo's rich natural resources. The limited passenger rail network between the two provinces leads to a heavy dependence on road transport, which increases road congestion and air pollution. The research explores how an HSR network that links the two provinces could improve transportation infrastructure, connectivity, and equitable economic growth. Which seeks to significantly reduce travel times, create job opportunities, and stimulate tourism and economic activities by connecting Pretoria to Musina through key towns such as Hammanskraal, Bela-Bela, Modimolle, Mookgopong, Polokwane, and Louis Trichardt. The project promises to create substantial employment opportunities with the potential for 81,539 construction jobs and 195,644 high-skilled jobs, with an economic return of R611.5 billion, and it will incorporate advanced technologies

like AI, IoT, RFID tags, HUD and ITS to optimize operations and lessen environmental impacts. The HSR project will connect Pretoria to Polokwane, and extend to Musina in two phases, targeting regional disparities and unemployment while providing a modern commuting option. Collaboration with local governments is essential for feasibility. By learning from global HSR projects and the Gautrain experience, this study outlines a roadmap for the HSR network, essential for sustainable regional development and socio-economic integration in South Africa.

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The author declares that no financial or personal relationships could have influenced this article's writing.

6.2 Author's Contributions

Mr A Sigama is the main author of this paper, while Prof. B Guo, Prof J Chakwizira and Dr T Gondo are the supervisors and co-authors of the paper.

6.3 Founding Information

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6.4 Data Availability

The data generated and analyzed in this study are available upon reasonable request from the corresponding author.

6.5 Disclaimer

The author confirms that their work does not infringe upon any existing copyrights.

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